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Analysis and Design of Weight Balancing System for Laser Velocimetry Traverse

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This technical memorandum describes the process of designing the weight balancing system which is an in-house effort to extend the lifting capability of the vertical axis of the Anomatic II system. The Anomatic II system is a programmable three-dimensional positioning controller used as a laser velocimetry traverse. The Anomatic II system is the prime mover and the weight balancing system is an add-on follower that derives its motion and speed in response to the Anomatic II system. The weight balancing system consists primarily of a pneumatic cylinder-steel cable mechanism which proves to be effective in lifting excessive weight, economic in construction and simple to operate.

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1. INTRODUCTION

The Anomatic II system[1] is a programmable positioning controller purchased from the Anorad Corporation. The system's operating features and procedures are described in detail in its instruction manual.

The weight balancing system, however, is an in-house designed feature being added to the vertical (or z-) axis of the Anomatic II system. The weight balancing system provides a means to increase the loading capacity of the combined weights of the table, the optical slab, the laser and its associated optics that can be mounted on the slab for the Laser Doppler Velocimetry (LDV) system or other aero-diagnostic equipment.

The table moves in the z-axis at a desired velocity by selecting an appropriate rpm of the servomotor-screw mechanism (henceforth called the servomechanism) which is contained in the Anomatic II system. The weight balancing system is basically a passive device which consists primarily of a pneumatic cylinder-steel cable mechanism (the pneumatic mechanism).

In order to alleviate the complexity of temporal synchronization and of velocity matching between these two mechanisms, no pneumatic controller is employed in the designed pneumatic mechanism. Therefore, that the weight balancing system is called a passive device becomes obvious. A set of engineering drawings of the weight balancing system is kept on file for reference, and drawing numbers are listed in Table I. All the purchased items and their suppliers are annotated on the drawings.

2. DESCRIPTION OF WEIGHT BALANCING SYSTEM

The pneumatic mechanism is shown in Figs. 1 through 4. Two side plates are designed to extend the existing frame of the Anomatic II system for supporting the cable sector which is also known as a rocker. The 10.5" arm of the cable sector is connected to a ball fitting on one end of the 0.25" diameter stainless steel cable, and the other plane end to the piston rod clevis of the air cylinder via two zinc plated malleable wire rope clips. The 21" arm is on the opposite side of the same cable sector, and arranged in a similar way except the plane end is attached to a 0.5" diameter eye bolt passing through an enlarged hole of 1.5" diameter on the optical slab, in turn, the eye bolt is anchored to the table. The large hole provides sufficient clearance for the optical slab to be easily adjusted with respect to the table without disturbing the alignment of optics already arranged on the optical slab.

The shop air has the maximum pressure of 100 psig at the source, and is made available at the wind tunnels in the

Table I : Engineering Drawings

Drawing No.	Title
89D001	Subassembly 1 of 2 Wt. Balancing Mechanism
89D007	Subassembly 2 of 2 Wt. Balancing Mechanism
89D002	Cable Sector
89B003	Cable Holder Block
89C004	Support Frame
89B005	Stationary Shaft
89B006	Tie Rod
89B008	Rod Clevis
89B009	Rod Clevis Pin
89B010	Base Plate

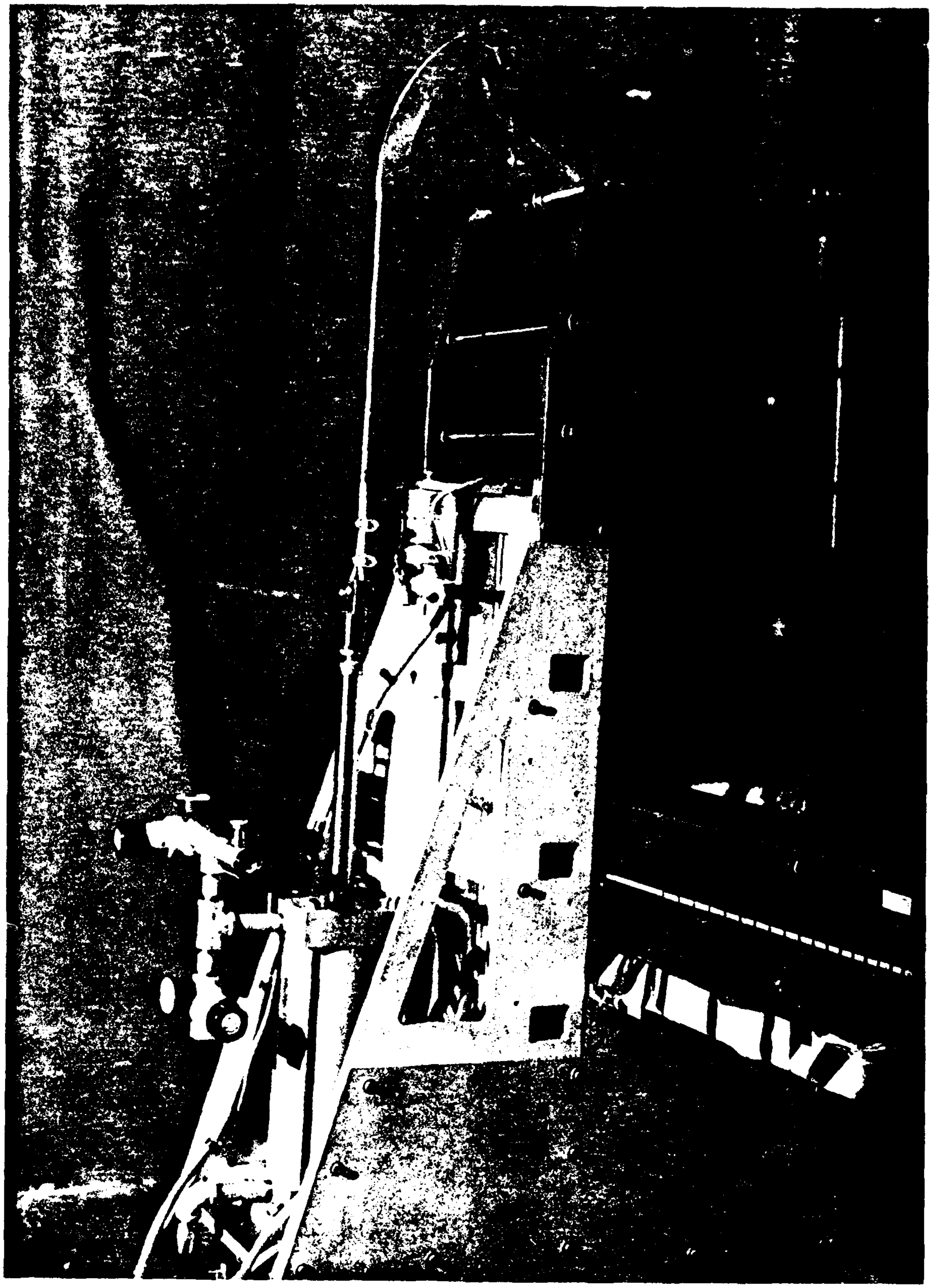


Fig. 1: WEIGHT BALANCING SYSTEM MOUNTED ON ANOMATIC II SYSTEM

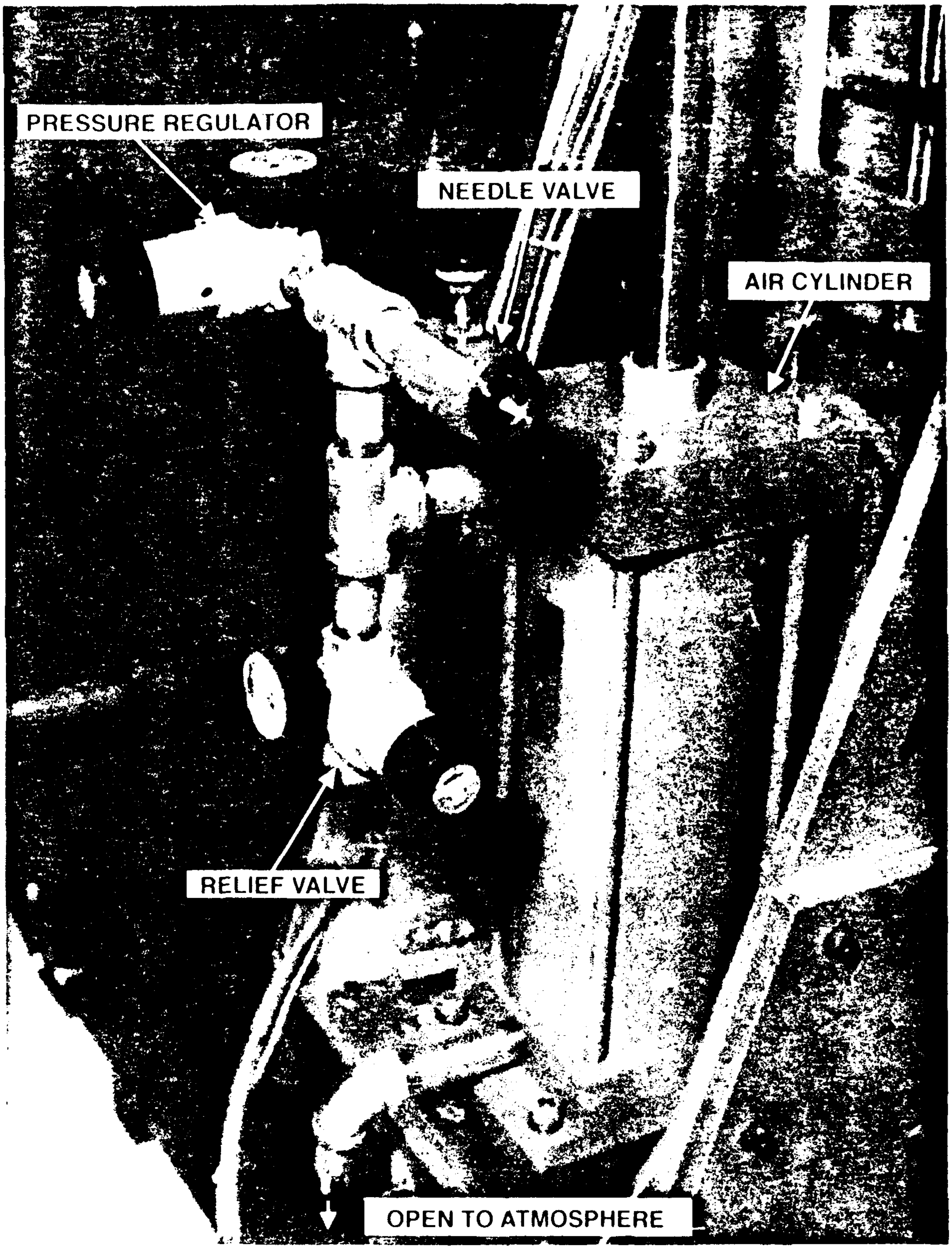


Fig. 2: PRESSURE REGULATING ASSEMBLY

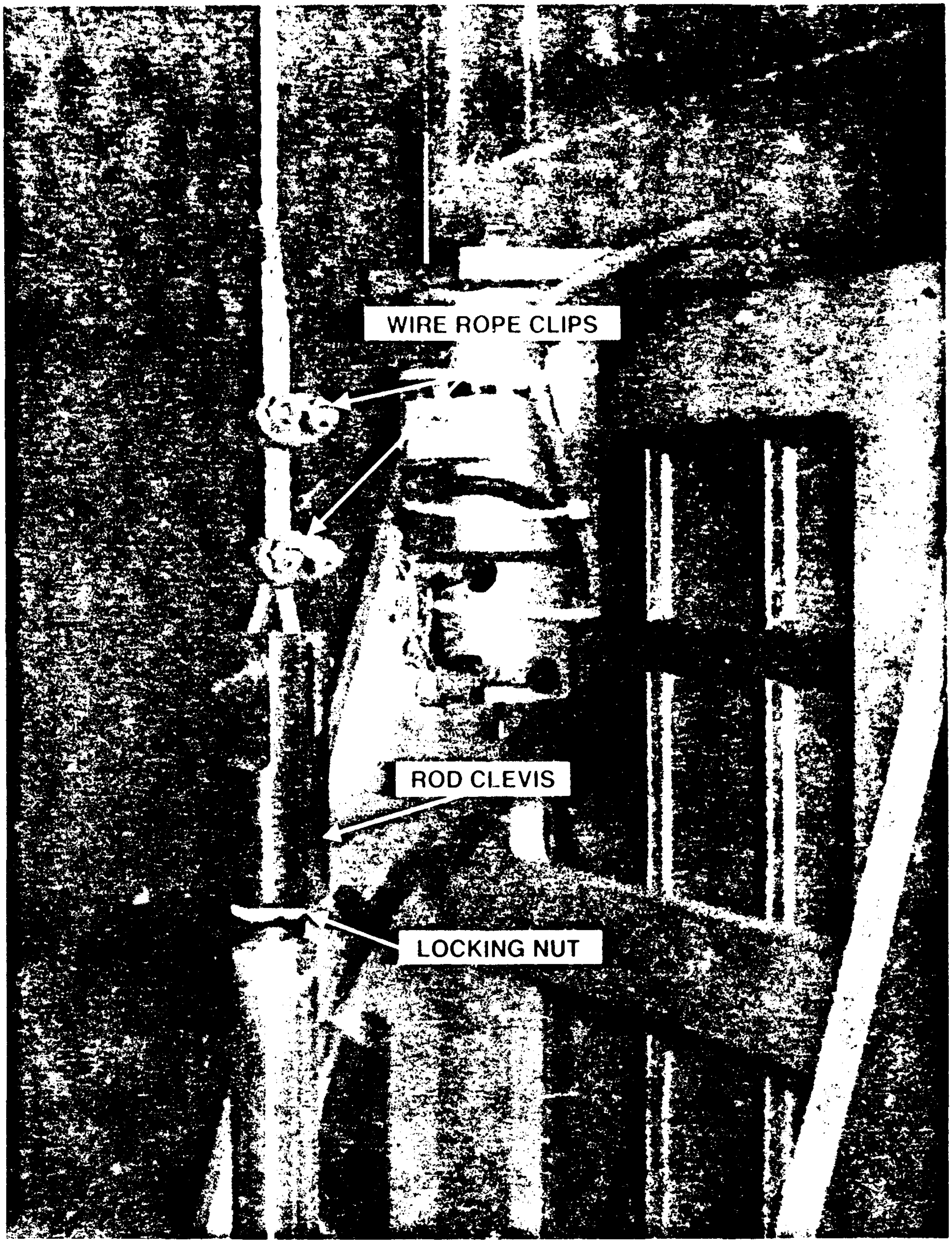


Fig. 3: AIR CYLINDER SIDE - WIRE ROPE ADJUSTMENT

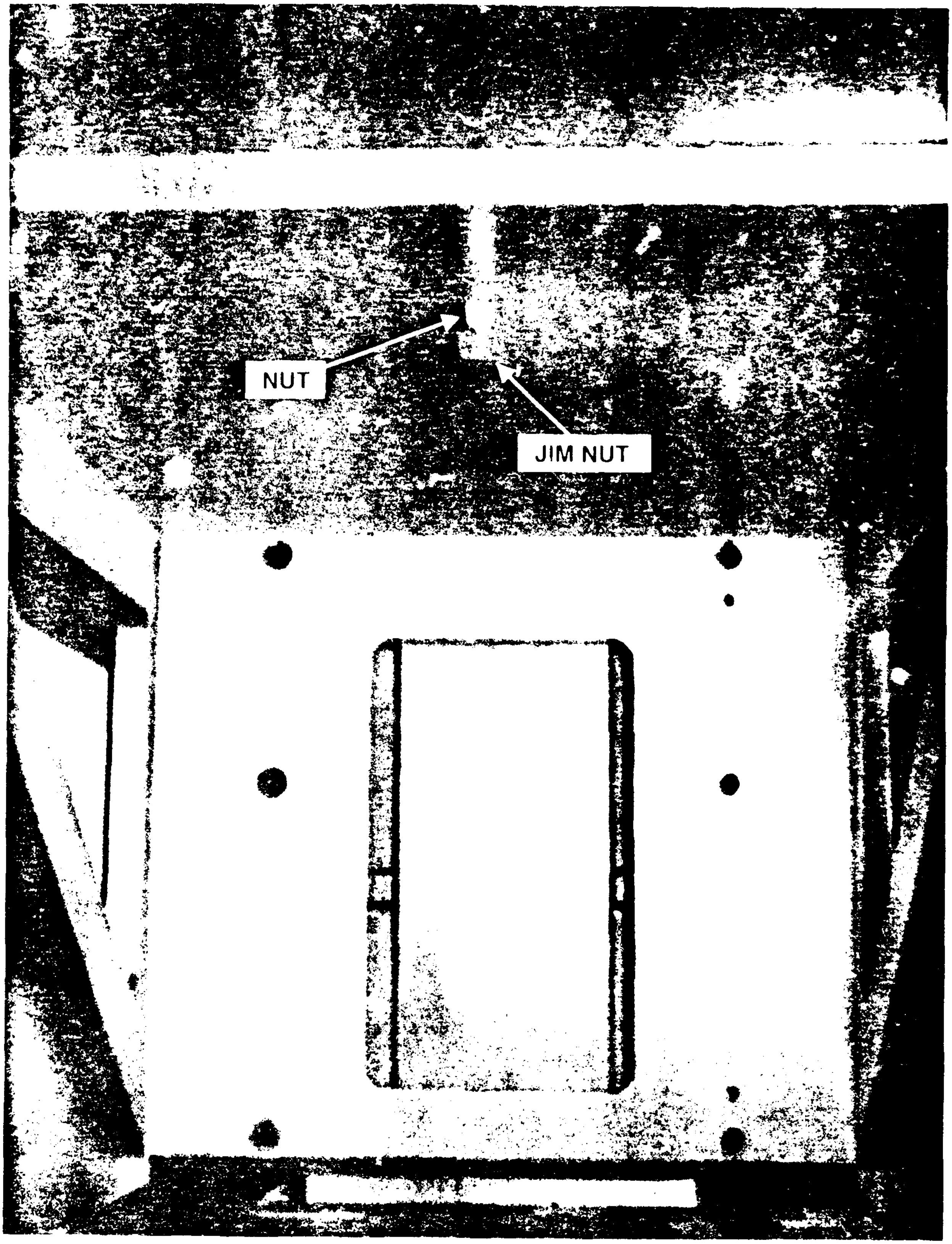


Fig. 4: TABLE SIDE - WIRE ROPE ADJUSTMENT

Aeromechanics Division. The compressed air can be introduced to the pressure regulator of the weight balancing system through a flexible hose with quick connection fitting.

The regulator fitted with a pressure gage is used to maintain a constant outlet pressure in spite of changes in the inlet air pressures and/or changes in the outlet flow requirements in the air cylinder of the weight balancing system.

A relief valve with a pressure gage and a needle valve are also installed in the pipe fittings of the weight balancing system. The relief valve is used to retard excessive air pressure build-up in the air cylinder and as a safety valve to prevent damage to the system components. The needle valve has a wide range of flow adjustment because of the fine threaded and tapered needle, and also provides a small amount of air leakage to keep the flow dynamically ready for action in the pressure system.

The coarse adjustment of the cable length can be accomplished through readjustment of the position of wire rope clips, whereas the fine adjustment of the cable tautness can be achieved by readjustment of the piston rod clevis and the locking nut on the air cylinder side, and by readjustment of the nut and the jim nut of the eye bolt on the table side.

3. SYSTEM OPERATION AND OPERATING PRINCIPLE

The servomechanism is the prime mover, and its directional movement as well as speed can be remotely controlled or preprogrammed from the floor console of the Anomatic II system. The pneumatic mechanism is a key part of the weight balancing system, and plays the vital function of a follower to lift the desired amount of excessive load acting on the servomechanism whenever the pneumatic mechanism is pressurized at a corresponding pressure setting. The word follower here means that the pneumatic mechanism derives its motion and speed in response to the servomechanism.

The air cylinder used in the weight balancing system has a 6" diameter piston and a 1.375" diameter piston rod on the pull side, whereas the push side is always open to the atmosphere. Since the steel cable is not designed for transmitting the compression force, the pull side of the air cylinder is not utilized, and the air cylinder serves as a single acting pneumatic device.

Assume that the combined weight of the piston and piston rod, as well as the static or kinematic frictional force, are neglected, then

$$P_{reg} = \frac{2F_{table}}{\frac{\pi}{4}[(6)^2-(1.375)^2]}$$

$$=0.07466F_{table}$$

where

P_{reg} = regulator pressure, psig,

F_{table} = amount of excessive load to be lifted, lb,

and the factor of 2 is the ratio of the rocker arm on the table side to that on the air cylinder side as mentioned earlier. Or conversely,

$$F_{table} = 13.39\ P_{reg}$$

For example, assume the table weight on the table side is 1000 lb. Using the pneumatic mechanism to balance the excess weight of 870 lb (i.e. to keep both wire ropes under tension: 130 lb on the table side and 260 lb on the cylinder side), it requires the regulator pressure to be set to 65 psig and the relief valve a couple of psig higher, say 67 psig.

When the servomechanism moves the table upward at a selected speed, the pressure regulator opens due to the lower pressure created inside the air cylinder, i.e.

$$P_{reg} > P_{cyl}$$

where

P_{cyl} = air cylinder pressure, psig.

At the same time the relief valve closes due to the higher pressure setting of the relief valve, i.e.

$$P_{rel} > P_{cyl}$$

where

P_{rel} = relief valve pressure, psig.

such that the piston moves downward.

Alternatively, when the servomechanism moves the table downward, the pressure regulator closes due to $P_{cyl} > P_{reg}$. While the relief valve opens due to $P_{cyl} > P_{rel}$ to bleed air to the atmosphere such that the piston moves upward.

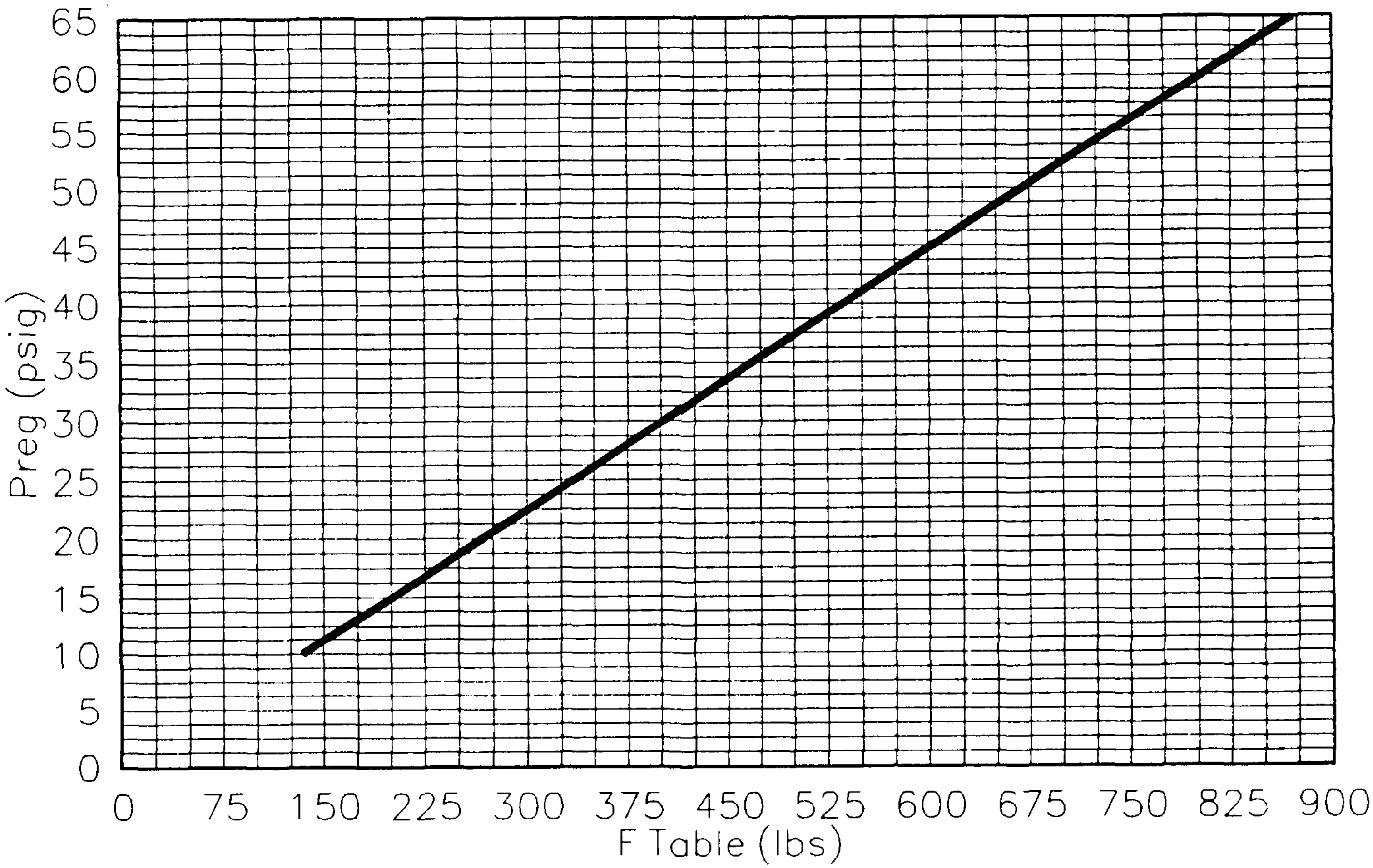
In both cases described above, the air cylinder tries to maintain a pressure of 65 psig,i.e.

$$P_{reg} = P_{cyl}$$

and to balance the excessive load of 870 lb on the table side.

P_{reg} vs F_{table} is shown in Fig.5 for convenient use at the wind tunnel facility.

Fig. 5: Regulator Pressure vs. Excessive Loads
Ftable = 13.39*Pressure



(Including optical slab, laser and its associated optics, but excluding table itself)

4. STRESS ANALYSIS[2] OF THE CRITICAL PART --- THE SHAFT

A grease packed and double sealed type of radial ball bearing with a 1.25" I.D. is press fit at the mid-position of a stationary shaft which spans 16" in length between two side plates.

Each end of the shaft is supported by one side plate, and secured with a 0.375" diameter set screw. The aforesaid bearing has a 2.5625" O.D., and is also press fit onto the hub of the rocker. The loading conditions of the rocker-cable mechanism are depicted in Fig.6.

Let us continue to use the input of the previous example as described in Section 3. Since the rocker rotates freely around the shaft by using a ball bearing, and no twisting moment exists in the shaft, the shaft can be considered as a circular beam with fixed ends under a combined transverse center load, F, as shown in Fig.7.

$$\begin{aligned} F &= F_{\text{table side}} + F_{\text{cylinder side}} \\ &= 870 + 1740 \\ &= 2610 \text{ lb} \end{aligned}$$

$\Sigma F = 0$,

$$\begin{aligned} R_1 &= R_2 \\ &= 1/2\ F \\ &= 1305 \text{ lb} \end{aligned}$$

$\Sigma M = 0$,

$$\begin{aligned} M_1 &= M_2 \\ &= 1/8\ Fl \\ &= 1/8\ (\ 2610 \times 16\ ) \\ &= 5220 \text{ in-lb} \end{aligned}$$

and

$$\begin{aligned} V_{A \to B} &= +\ 1/2\ F \\ &= 1305 \text{ lb} \\ V_{B \to C} &= -\ 1/2\ F \\ &= -\ 1305 \text{ lb} \end{aligned}$$

where

R_1 and R_2 are the reaction forces, lb;
M_1 and M_2 are the constraining moments, in-lb;

and

$V_{A \to B}$ and $V_{B \to C}$ are the vertical shearing forces, lb.

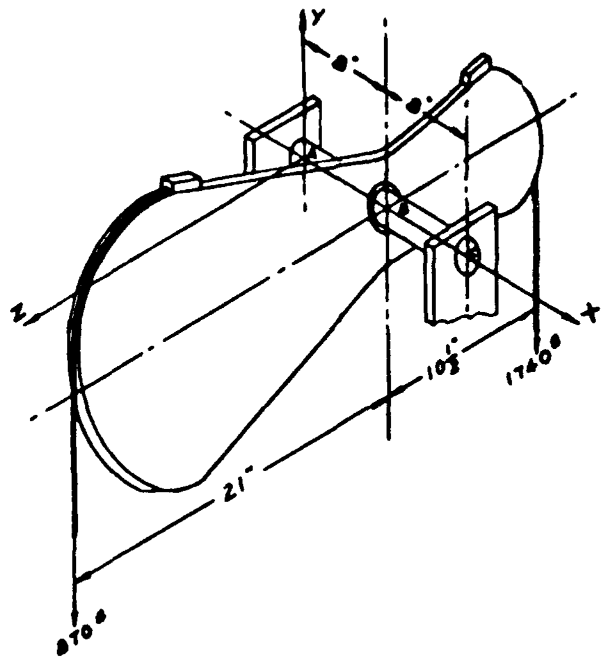
The maximum bending moments are

$$\begin{aligned} M_{max} &= +1/8\ Fl \\ &= 5220 \text{ in-lb at B} \end{aligned}$$

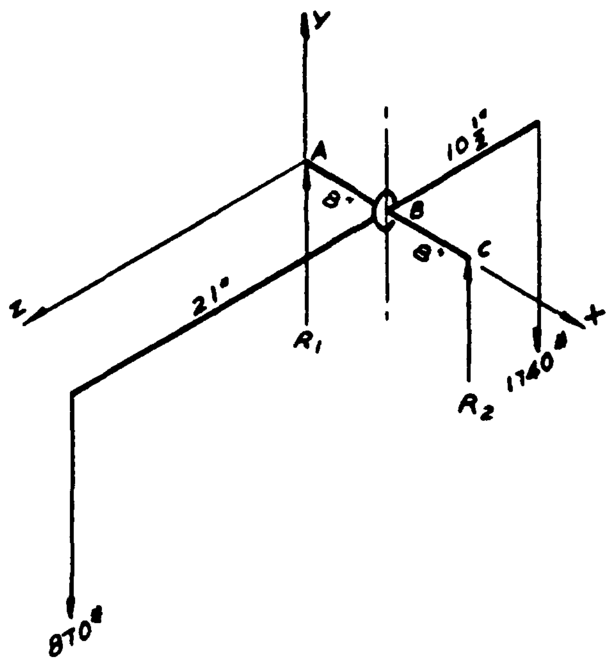
and

$$\begin{aligned} M_{max} &= -1/8\ Fl \\ &= -5220 \text{ in-lb at A and C} \end{aligned}$$

The shear and moment diagrams for the shaft of Fig.7 are shown in Fig.8. The maximum deflection is



(a) A Three-Dimensional Rocker-Cable Mechanism



(b) An Idealized Model of The Mechanism

Fig. 6. Loading Conditions of Rocker-Cable Mechanism

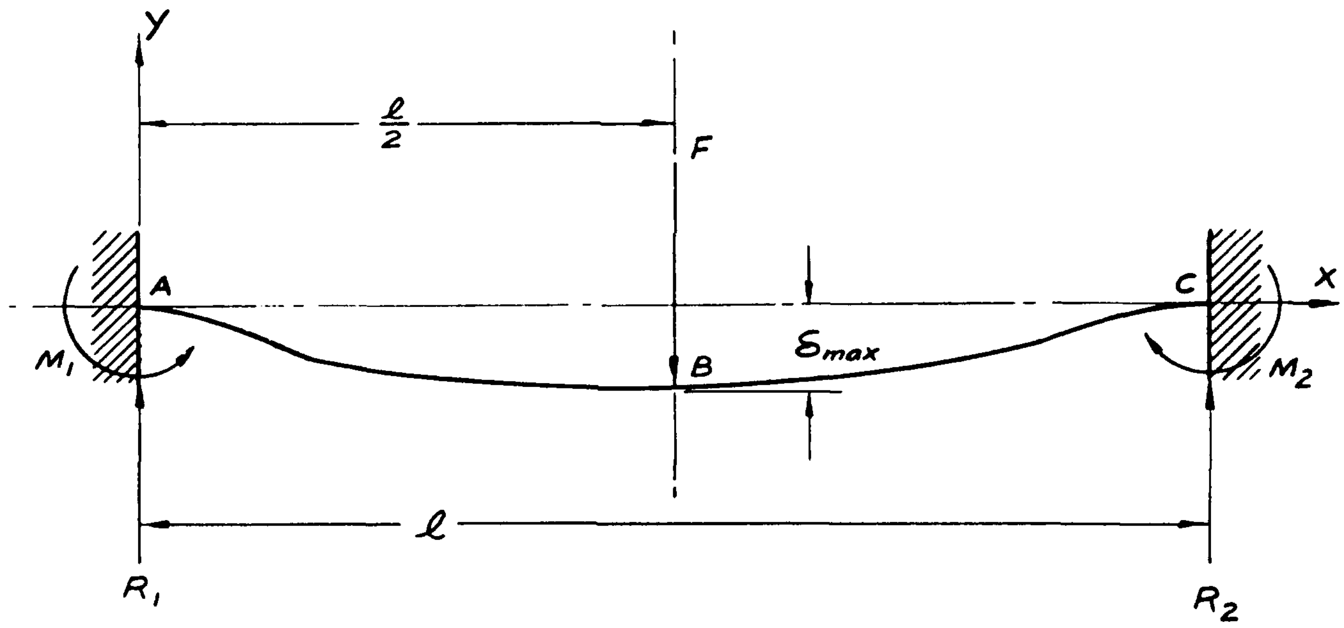


Fig. 7. Forces and Moments of Fig. 6(b) as Projected on The X-Y Plan

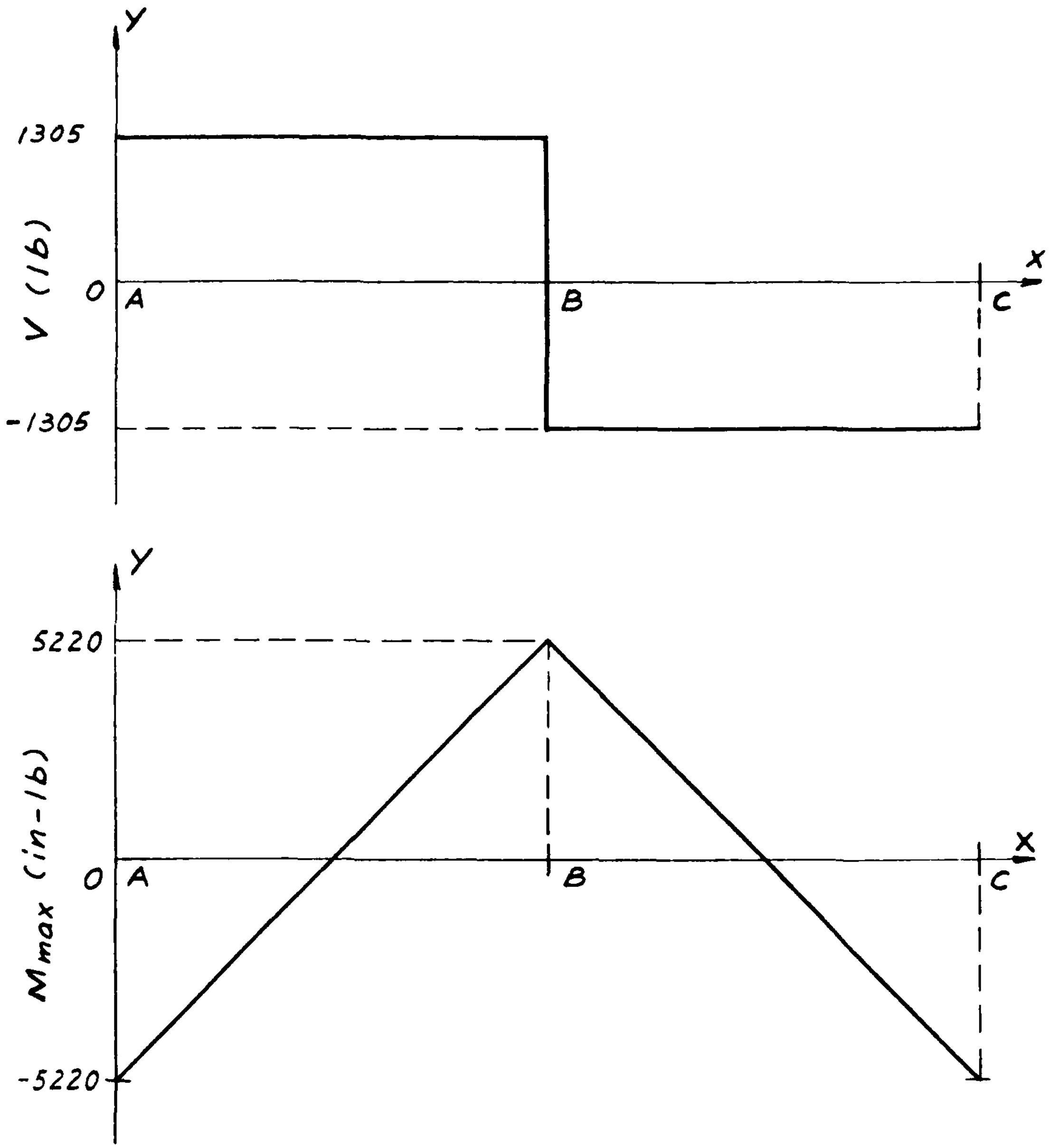


Fig. 8. Shear and Moment Diagrams

where

$$\delta_{max} = \frac{Fl^3}{192EI}$$

E = Young's modulus of elasticity
= 30 x 10^6 psi for steel

$$I = \text{moment of inertia of an area}$$
$$= \frac{\pi}{64} \times d^4 \text{ for shaft}$$
$$= \frac{\pi}{64} \times (1.25)^4$$
$$= 0.1198\ in^4$$

and

d = diameter of shaft, in

Substituting, we have

$$\delta_{max} = -\frac{2610(16)^3}{192 \times 30 \times 10^6 \times 0.1198}$$

= -0.0155" at **B**

where (-) sign denotes the deflection in the downward direction.

The maximum fiber stress at points most remote from the neutral axis (i.e. at the radius,r) is given by the flexural formula

$$S_{max} = \frac{M_{max}(\pm r)}{I}$$
$$= \frac{5220(\pm 0.625)}{0.1198}$$
$$= \pm 27230\ psi$$

where (+) sign denotes the lower fiber of shaft in tension, and (-) sign the upper fiber in compression.

The ultimate tensile strength is usually taken as 60000 psi for steel, therefore, the safety factor of tensile strength is

$$f_t = \frac{60000}{27230}$$

$$= 2.2$$

The maximum shear of a circular cross section is 33 percent larger than the average value obtained by dividing the shear force, $V_{A\to B}$ or $V_{B\to C}$ by the cross-sectional area, i.e.

$$\tau_{max} = \frac{4V}{3A}$$

where

$$\begin{aligned} A &= shaft\ area \\ &= \frac{\pi}{4} d^2 \\ &= \frac{\pi}{4}(1.25)^2 \\ &= 1.2272\ in^2 \end{aligned}$$

Substituting,

$$\begin{aligned} \tau_{max} &= \frac{4\times1305}{3\times1.2272} \\ &= 1420\ psi \end{aligned}$$

The ultimate shear strength for steel is usually taken as half the value of the ultimate tensile strength, thus the safety factor of shear is

$$\begin{aligned} f_\tau &= \frac{30000}{1420} \\ &= 21.1 \end{aligned}$$

The above stress analysis simply indicates that failure of the shaft will only occur because of the bending rather than the shear. It is recommended that the combined load of the table slab and the optical equipment (excluding the weight of table itself, 130 lb) should be less than or equal to 870 lb to be on the safe side.

5. MAINTENANCE

The grease packed and double sealed ball bearing has a rated radial capacity of 2640 lb at 50 rpm, and a maximum thrust load of 740 lb. The indicated load ratings are based on 2500 hours average life. If the loads and rpm decrease, the average life will increase. This bearing is essentially maintenance free throughout its useful life. The replacement can be accomplished by press fitting another new bearing.

The compressed air regulator, the relief valve, and the air cylinder are off-the-shelf items[3]. Their respective instruction manuals contain information about operation, specifications, warnings, installation, adjustment, disassembly, cleaning, reassembly, and repair kit installation. These bulletins are kept on file for further reference.

6. CONCLUSION

In the conceptual design, different methods of balancing weight were considered: dead weight, pulleys, lever, electrical and pneumatic devices. Other factors are also examined: the space limitation around the various wind tunnels and the availability of power sources. It was finally decided to use the combination of pneumatic cylinder and lever for achieving the desired result of a weight balancing system without significantly increasing the weight and operating complexity of the Anomatic II system. Most importantly, the pneumatic mechanism is compact and complementary to the existing Anomatic II system. It is understood that the pneumatic mechanism of the weight balancing system reduces the loading on the servomechanism of the Anomatic II system in the vertical (or z-) axis only, but adds less than 100 lb to the transverse (or x-) and the longitudinal (or y-) axis. The weight balancing system proves to be an effective, economic and simple system.

REFERENCES

1. "Anomatic II Positioning Controller Operating & Programming Instruction Manual," Anorad Corporation, 110 Oser Ave., Hauppauge, NY 11788, 1984.

2. S. Timoshenko, "Strength of Materials," Part I, D. Van Nostrand Company, NY, 1953.

3. Boston Gear Catalog 100, 14 Hayward Street, Quincy, MA 02171, 1985.